

# Charmonium dynamics in $dA$ and $AA$ at RHIC and LHC

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**Abstract.** We discuss features of charmonium suppression at  $\sqrt{s} = 200$  GeV within the framework of the Glauber-Gribov theory and the comovers interaction model. The latter approach has been extended by allowing for secondary charmonium production due to recombination of  $c\bar{c}$  pairs in the medium, estimated from  $pp$  data at the same bombarding energy. Centrality and rapidity dependence of the nuclear modification factor for  $J/\psi$  in  $d+Au$ ,  $Cu+Cu$  and  $Au+Au$  collisions at RHIC are reproduced without fitting a single model parameter. A strong suppression of  $J/\psi$  is predicted for LHC energies.

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## 1. Introduction

Charmonium production off nuclei is one of the most promising probes for studying the properties of matter created in ultrarelativistic heavy-ion collisions. It was realized long time ago, that only collisions where a large density of particles is produced in the central region give rise to an anomalous  $J/\psi$  suppression, i.e. above the one observed in  $pA$  collisions. The anomalous suppression was advocated as a signal of charmonium melting in a thermalized quark-gluon plasma, but can also be described as a final state interaction of the  $J/\psi$  with co-moving matter, of both partonic and hadronic nature, see e.g. [1, 2]. At RHIC, charmonium has been measured for several collision systems and both at forward and mid-rapidities, and hence provide unique insights into the production and interaction of charmonium in nuclear environments at very high energies.

We present an approach based on Glauber-Gribov theory, which encompasses several nuclear effects for  $J/\psi$  suppression in  $dA$  collisions, supplemented with additional

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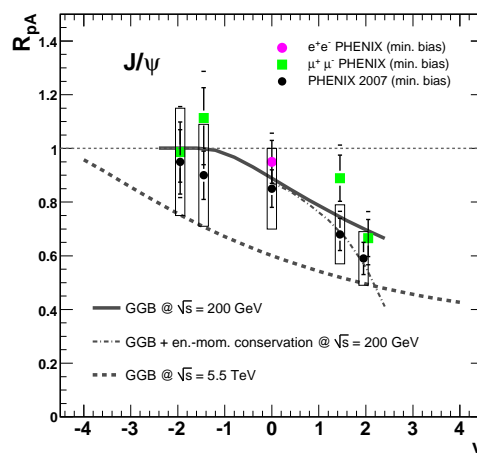
interaction with comovers in the final state in  $AA$ , which also allows for secondary  $J/\psi$  production from recombination.

## 2. Baseline: charmonium in $dA$ collisions

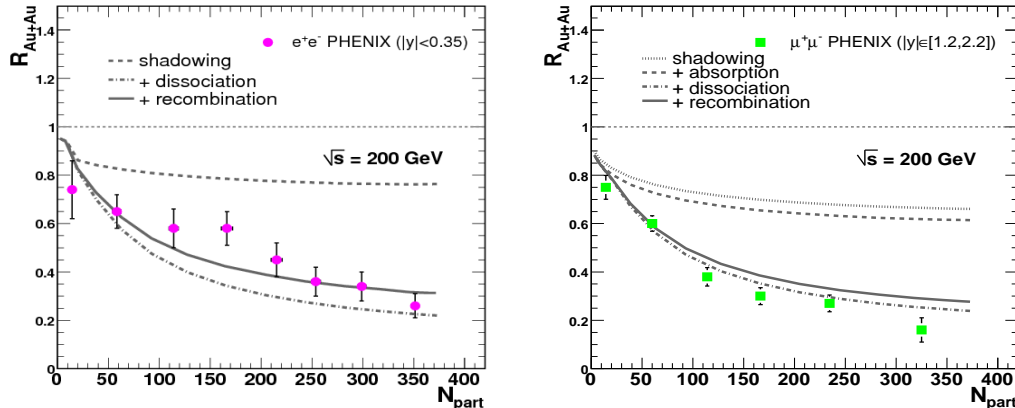
At lower energies, nuclear suppression of charmonium in  $pA$  collisions was attributed to the successive interaction of the produced  $J/\psi$  (or, rather, the pre-resonant  $c\bar{c}$  pair) with the surrounding nuclear matter. In the Glauber model, this mechanism could be quantified by an absorptive cross section,  $\sigma_{abs}^\psi$ , which was found to be about 5 mb at  $\sqrt{s} = 19$  GeV [3]. Within this semiclassical picture, most models predicted a growth of absorption with energy, see e.g. [4]. On the contrary, measurements of  $J/\psi$  production in d+Au collisions at RHIC [5, 6] revealed a significant reduction of nuclear absorption compared to measurements at lower energies.

The RHIC results signal a breakdown of the semiclassical probabilistic picture of ordered multiple scattering, and is in line with predictions from the relativistic Glauber-Gribov theory of nuclear interactions [8, 9]. Above a certain critical energy  $E_M$  the incoming hadron can fluctuate into a state containing the both heavy  $c\bar{c}$  state and light quarks and gluons long before the collision with the nucleus takes place. In the coherent limit, both the soft partons of the fluctuation and the heavy  $c\bar{c}$  system itself can interact almost simultaneously with several nucleons in the target. Schematically, the former process leads to shadowing of nuclear parton densities and dominates at mid-rapidity while the latter imposes limits from energy-momentum conservation in the forward region. In other words, the diagrams involving multiple scattering ordered in the longitudinal direction, the so-called Glauber-type diagrams, are suppressed at  $E > E_M$  and hence nuclear absorption drops out. Note, that we do not assume any diminution of the absorptive cross section.

We refer to [10, 11] for further details on the Glauber-Gribov theory and analysis of RHIC data. In figure 1 we compare calculations of gluon shadowing [12] alone (solid



**Figure 1.** Rapidity dependence of  $J/\psi$  suppression for minimum bias d+Au collisions at RHIC and predictions for p+Pb collisions at LHC. Data are taken from [5, 6].



**Figure 2.** Centrality dependence of  $J/\psi$  suppression in Au+Au collisions at RHIC at mid- (left figure) and forward (right figure) rapidities. Data are taken from [7].

curve) and additionally with energy-momentum conservation (dash-dotted curve) to data on  $J/\psi$  suppression in d+Au collisions at  $\sqrt{s} = 200$  GeV [5, 6]. This constitutes the baseline in the search for the origin of anomalous suppression in  $AA$  collisions.

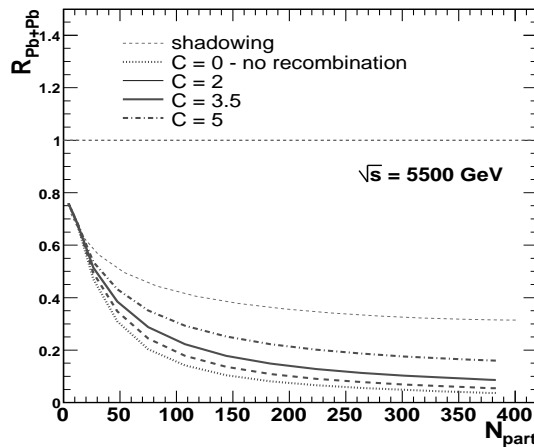
### 3. Charmonium recombination and dissociation in $AA$

One finds a large density of particles in central  $AA$  collisions at RHIC. In addition to the nuclear effects present in the smaller  $pA$  collisions described above, one should also take into account the possible interaction of  $J/\psi$ 's with co-moving matter produced in the collision. This interaction can be quantified by a simple rate equation which, assuming boost-invariant longitudinal expansion, takes the form

$$\tau \frac{dN_{J/\psi}}{d\tau} = -\sigma_{co} [N^{co} N_{J/\psi} - N_c N_{\bar{c}}] , \quad (1)$$

where  $N^{co}$ ,  $N_{J/\psi}$  and  $N_{c(\bar{c})}$  denote the density of comovers, hidden and open charm at the impact parameter of the initially produced  $J/\psi$ , respectively. The first term in (1) is responsible for charmonium dissociation while the second gives rise to secondary  $J/\psi$  production due to recombination. The interaction cross section  $\sigma_{co}$  was found at SPS to be 0.65 mb in a model where charmonium recombination was neglected due to the small density of open charm [13].

Calculations including both terms in (1) and the same  $\sigma_{co}$  were presented in [14]. The density of charmonium and open charm at RHIC was inferred from measurements in  $pp$  collisions at the same energy [15, 16] (the density of open charm at forward rapidity was taken from PYTHIA). Results for  $J/\psi$  suppression in Au+Au collisions at both mid- and forward rapidities ( $\eta = 2.2$ ) at RHIC are compared to experimental data [7] in figure 2. Note, that no parameters were fitted to obtain such good agreement with the experimental data. In particular, the stronger suppression at forward rapidities is a result of strong initial state suppression and smaller recombination. Calculations for Cu+Cu collisions at the same energy are also matching the experimental data. We refer to [14] for further details of the calculation.



**Figure 3.** Predictions for the centrality dependence of  $J/\psi$  suppression at mid-rapidity in Pb+Pb collisions at LHC.

Recombination effects will be of crucial importance in Pb+Pb collisions at  $\sqrt{s} = 5.5$  TeV. Predictions for  $J/\psi$  suppression at LHC have been made assuming  $d\sigma_{c\bar{c}}/dy \approx 1$  mb at mid-rapidity and the non-diffractive  $pp$  cross section  $\sigma_{pp} = 59$  mb [14], with  $\sigma_{co}$  kept fixed. This corresponds to  $C = 2.5$  in figure 3. In our model, this stands for four times stronger recombination effects at LHC than at RHIC. The strong and almost impact parameter independent  $J/\psi$  suppression is mainly due to strong initial state gluon shadowing, depicted with a dotted curve in figure 3, and because of a large density of comovers leading to strong dissociation. This is in stark contrast to predictions of enhanced production of  $J/\psi$  obtained in a model assuming thermalization of the heavy quarks with the entire partonic system formed at a given impact parameter [17].

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